

CHAPTER 5

DISCUSSION AND CONCLUSION

5.1 Volcanic Lithofacies and Stratigraphy

The Ban Sap Sawat basaltic rocks, part of Wichian Buri basalt, Phetchabun Province, have been erupted in the Miocene and mainly occur as *in situ* floats in low lands and as outcrops in highlands, covering an area of about 45 km². Two main volcanic facies, i.e. coherent facies basalt (lava flow) and incoherent facies basalt (breccia), have been recognized in the exposures of Ban Sap Sawat basaltic suite. The incoherent facies basalt consists of poorly sorted, angular to subrounded, basalt fragments, sitting in the finer-grained matrix, which is largely made up of highly altered, glassy fragments. Pillow lobes and pillow fragments, with concentric and radial joints and/or glassy skins, have also been observed as *in situ* float rocks. The core samples penetrated in five drill holes show three main types of volcanic lithofacies, including coherent facies basalt, clast-/matrix-supported incoherent basalt and volcanogenic facies sandstone and conglomeratic sandstone with glassy clasts.

5.2 Petrography

The Ban Sap Sawat coherent facies basaltic lava samples from outcrops and core samples have dark gray to black colors and commonly show slightly to moderately porphyritic textures; a seriate texture is uncommon. The phenocrysts/microphenocrysts are mainly olivine and plagioclase that sit in the holocrystalline or hypohyaline groundmass. The holocrystalline groundmass consists mainly of felted plagioclase laths, with subordinate clinopyroxene and olivine, and a small amount of Fe-Ti oxide grains. The hypohyaline groundmass consists mainly of felted plagioclase laths and tachylite, and a small amount of olivine grains. The

seriate-textured rocks are made up largely of plagioclase and clinopyroxene that almost totally show ophitic/subophitic relationships.

The coherent facies cobble- to boulder-grade, basaltic clasts from clast-/matrix-supported incoherent basalt commonly show slightly to strongly porphyritic textures with phenocrysts/microphenocrysts of plagioclase and olivine; seriate-textured clasts are uncommon. The phenocrysts/microphenocrysts sit in the hypohyaline groundmass consisting mainly of plagioclase laths and tachylite (dark brown to black volcanic glass), and small amounts of olivine, clinopyroxene and Fe-Ti oxide grains. Some samples may show hyalophitic-textured groundmass, consisting mainly of tachylite, with subordinate felty plagioclase laths and olivine grains. Quench crystals and skeletal crystals, have been observed in the volcanic glass. The glassy groundmass may have vesicles and cavities that are filled by common zeolites and/or uncommon clay minerals. The seriate-textured clasts are made up of mainly felted plagioclase laths, with subordinate interstitial materials, including volcanic glass and quench crystals, and olivine grains.

The matrix-supported incoherent basalt is highly altered to brownish clay and glassy clasts. These samples are composed abundantly of clay- to sand-grade clasts, with minor granule- to pebble-grade clasts. The gravel-grade clasts are much less altered than the finer-grained matrix, which turns to a yellowish brown color. The gravel-grade clasts are strongly vitrophyric basalt, with olivine and plagioclase phenocrysts/microphenocrysts. The groundmass of vitrophyric basalts show a glassy texture that is made up largely of yellowish brown sideromelane and minor quench crystals of olivine and plagioclase. The dark or blackish brown volcanic glass (tachylite) is uncommon in the vitrophyric basalt. At rim of individual clasts, the original groundmass sideromelane has been commonly replaced by dark brown palagonite, with minor bluish and bluish green palagonite. Vesicles are variably present in some vitrophyric clasts, and are sealed by zeolites and clay minerals. The glassy walls of vesicles are commonly replaced by brownish/bluish green palagonite and/or chloritic materials. The matrix of basalt breccia is composed mainly of vitrophyric clasts similar to gravel-grade clasts, glassy fragments and crystal

fragments, i.e. olivine and plagioclase. The original sideromelane in these vitrophyric clasts has been commonly replaced by dark brown palagonite and/or green palagonite/chloritic material. The whitish minerals, observed in core samples as cementing material and as cavity- and fracture-infillings, are zeolites and clay minerals.

5.3 Geochemistry

Chemical analyses have been carried out on the samples of coherent facies basalt, cobble- and boulder-grade, basaltic clasts from clast-supported incoherent facies basalt, and matrix-supported incoherent facies basalt, and the results show that they are not significantly different. This implies that they have been solidified from the same magma but have different cooling rates as previously suggested by petrographic evidence.

The Ban Sap Sawat basaltic rocks, inferred from the geochemical data for coherent facies basalt, and cobble- and boulder-grade, basaltic clasts from incoherent facies basalt, are transitional tholeiite. They have 47.59 ± 0.50 wt% SiO_2 , 3.24 ± 0.23 wt% Na_2O , 0.59 ± 0.15 wt% K_2O and 10.69 ± 0.29 wt% FeO^* , with Nb/Y and FeO^*/MgO ratios in ranges of 0.11-0.38 (0.22 ± 0.07 on average) and 1.19 – 1.47 (1.29 ± 0.07 on average), respectively, and normative nepheline up to 4.44 wt%. Their mg# in a range of 0.36 - 0.45 signify that the studied basaltic samples do not represent a primary magma derived from partial melting of a normal mantle (Irving and Green, 1976; Frey *et al.*, 1978; Wilson, 1989). The nature of evolved basalt well-supported by relatively low concentrations of Ni (79 – 176 ppm, 139 ± 27 ppm on average) and Cr (207 – 369 ppm, 331 ± 42 ppm on average) (Frey *et al.*, 1978; Wilson, 1989), and their Zr/ TiO_2 values (0.009 – 0.013, 0.010 ± 0.001 on average).

In spite of the limited compositional ranges, the coherent facies basaltic rocks show broad negative trends for FeO^* and TiO_2 but a broad positive trend for Al_2O_3 . The Al_2O_3 depletion with decreasing MgO content implies that the trend was likely to be controlled by suppression of plagioclase and mafic minerals. The

phenocryst/microphenocryst assemblages signify that the minerals involved in fractionation are plagioclase and olivine. An inference can be drawn here that the studied, coherent facies volcanic rocks are evolved transitional tholeiite that have experienced a small degree of plagioclase and olivine fractionation.

The Ban Sap Sawat transitional tholeiite has common geochemical characteristics between mid-ocean-ridge basalts and within-plate basalts. Their chondrite-normalized REE patterns show slightly LREE enrichment and relatively HREE depletion, with chondrite-normalized La/Sm, Sm/Yb and La/Yb in ranges of 2.86 - 3.86, 1.44 - 2.13 and 4.79 - 6.16, respectively. Their N-MORB normalized multi-element patterns show a step-like patterns, with strong Sr, K, Rb, Ba and Th enrichment, and Ta – Nb troughs. The chondrite-normalized REE patterns and N-MORB normalized multi-element patterns are closely analogous to the Early-Middle Miocene, Central Sinkhote-Alin and Sakhalin basalts from northeastern margin of the Eurasian continent (Okamura *et al.*, 2005), which were erupted in a continental rift environment. It is well-recognized that two episodes of volcanism were developed in the Tertiary continental within-plate basalts. The older episode commonly yielded tholeiitic basalts and transitional tholeiitic to alkalic basalts (e.g. Okamura *et al.*, 2005), while the younger episode transitional tholeiitic to strongly alkalic basalts (e.g. Okamura *et al.*, 2005; Abdel-Rahman and Nassar, 2004; Monghazi, 2003). As a consequence, the Ban Sap Sawat transitional basaltic magma might have been generated in the older episodic volcanism, while the alkalic basaltic magma to the east of the Ban Sawat study area the younger episodic volcanism.

5.4 Origin of Breccia

Breccia is a descriptive term for rock that consists of angular, gravel-sized fragments embedded in the matrix of similar or different constituents, regardless of origin and composition. In volcanic terranes, a number of genetic terminologies of breccia have been proposed. These include tectonic breccia, sedimentary breccia, impact breccia, hydrothermal breccia and igneous breccia. Tectonic breccia is that developed from brittle rocks, formed as a result of crustal movements and produced

by lateral or vertical pressure. Fault and fold breccia is classified as tectonic breccia. Sedimentary breccia is a type of sedimentary rock, formed by rock fall, slide/slump, mudflow, debris flow, grain flow, liquefied (fluidized) flow, and turbidity current. Their clasts may be either pyroclastic or epiclastic. Impact breccia is a fairly rare form of breccia and formed during meteorite impact. In contrast to the other genetic types of breccia, they are composed primarily of clasts of country rocks, melted rock fragments, tektite (glass ejected from the impact crater) and exotic fragments (derived from the impactor itself). Hydrothermal breccia is usually formed by highly pressured hydrothermal fluids. They are typical of epithermal ore environment and are intimately associated with intrusive-related ore deposits such as skarn, greisen and porphyry-related mineralization. Igneous breccia can be separated into two main categories, i.e. volcanic and intrusive breccia. Volcanic breccia is that formed by explosive eruption of lavas and rocks that are entrained within the eruptive column, and/or non-explosive fragmentation of flowing lavas. The former gives rise to pyroclastic breccia, while the latter leads to autobreccia. The autobreccia formed by quench fragmentation is known as hyaloclastite. The mixed resulted of steam explosion and quench fragmentation may yield blocky peperite at the contact between lava and unconsolidated sediments. Intrusive breccias are those produced by intrusive processes, commonly associated with plutons or porphyry stocks, and uncommonly kimberlite pipes. Some autobreccia and blocky peperite is intrusive breccia.

The Ban Sap Sawat basaltic suite comprises three main volcanic and volcanogenic sedimentary facies, namely coherent facies basalt, incoherent facies basalt, and volcanogenic facies sandstone and conglomeratic sandstone. The stratigraphic positions of these rocks in individual drill holes are summarized in Figure 5.1. The similarity of coherent facies basalt and incoherent facies basalt, in terms of phenocryst/microphenocryst assemblage (olivine + plagioclase) and chemical compositions, signifies that both the coherent facies basalt and incoherent facies basalt have been formed from the same continental within-plate, transitional tholeiitic magma at pressures less than 8 kbars (e.g. Thompson, 1972; Hughes, 1982). The

holocrystalline to hypohyaline groundmass of coherent facies basalt and the glassy to hypohyaline clasts of incoherent facies basalt signify that the former has slower cooling rates than the latter, which is the product of autobrecciation formed by the interaction between hot magma and cold water (quenching). Pillow lobes and pillow fragments as observed in the field are evidenced for subaqueous lava flows. The existence of peperite, i.e. mudstone with chaotic basaltic patches, in drill hole CD4BII-D002 also signifies that the basaltic lava flows were emplaced on wet sediments. Accordingly, the incoherent facies basalt is autobreccia produced by quench fragmentation. During the emplacement of subaqueous lava flows, the cores of coherent facies basalt may be overlain by carapace of incoherent facies basalt. Figure 5.2 gives the architecture of contemporaneous volcanic facies that develop in association with the emplacement of subaqueous lava flows. The interlayers of coherent facies basalt and incoherent facies basalt, with peperite at the bottom in drill holes CD4BII-D003 might be located at site 1, whereas the incoherent facies basalt in drill holes CD4BII-D001 and CD4BII-D004 at site 2. The interlayers of coherent facies basalt and incoherent facies basalt, and the underlying, volcanogenic sandstone and conglomeratic sandstone in drill hole CD4BII-D002 and CD4BII-D005 are not contemporaneous in origin. The earlier formation of volcanogenic sandstone and conglomeratic sandstone might be located at site 3, while the later formation of coherent facies basalt and incoherent facies basalt at site 2. For these reasons, the incoherent facies basalt and the volcanogenic sandstone and conglomeratic sandstone in this project are either clast-supported or matrix-supported *in situ* hyaloclastite, and resedimented hyaloclastite, following the nomenclature given by McPhie *et al.* (1993). In addition, the Wichian Buri alkalic basalts are evidently underlain by the Tertiary sediments that contain Viviparous bed (Jungyusuk and Sinsakul, 1989). This signifies that the studied hyaloclastite might have been formed in a fresh-water environment.



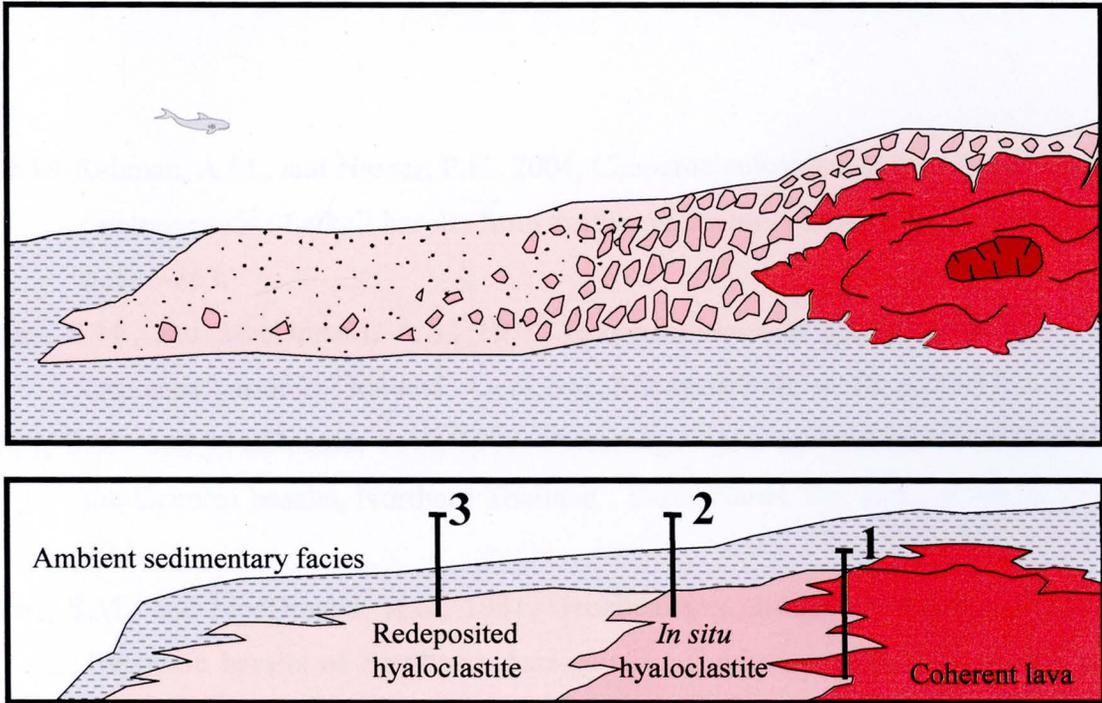


Figure 5.2 Contemporaneous volcanic facies that develop in association with the emplacement of subaqueous lava flow (after McPhie *et al.*, 1993). Also shown are the possible sites for drill holes CD4BII-D003 (1), CD4BII-D001 and CD4BII-D004 (2), and CD4BII-D002 and CD4BII-D005 (1 and 3).